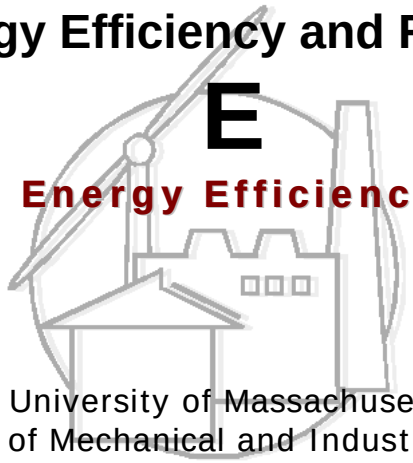
Center for Energy Efficiency and Renewable Energy

C E E R E

Building Energy Efficiency Program



University of Massachusetts
Department of Mechanical and Industrial Engineering
160 Governors Dr.
Amherst, MA 01003-9265

Computer Modeling of Heat Transfer and Comparison for PVC Casement Window – U-Factor and CR Simulations Using WINDOW 5 and THERM 5

Prepared by:

Yunhua Yang
Dr. Charlie Curcija
Dr. Mahabir Bhandari

June 2002

DESCRIPTION OF THE SPECIMEN

The product selected for simulation is a nominal 2'0" wide by 4'0" PVC casement window, manufactured by Anlin Industries. The specimen was tested by ATI from York, PA. The standardized tested U-factor, reported by ATI, is 0.31 Btu/h-ft^2-F (see Appendix C).

Thermo physical properties of different frame material are given in Table 1 and schematic representation of the material locations for a jamb cross section is shown in Figure 1. AutoCAD drawings of the specimen is given in Appendix B.

The glazing was double-glazed, consisting of nominal 0.875" thick insulating glazing system fabricated from two 0.125" sheets of glass with a 0.036 emittance Low 'E' coating at surface 2, and 0.650" air space. The detailed reports from Window5 are given in Appendix (A)

The spacer was a single seal Swiggle Strip spacer from True Seal company. The geometry and spacer details are given in Appendix D.

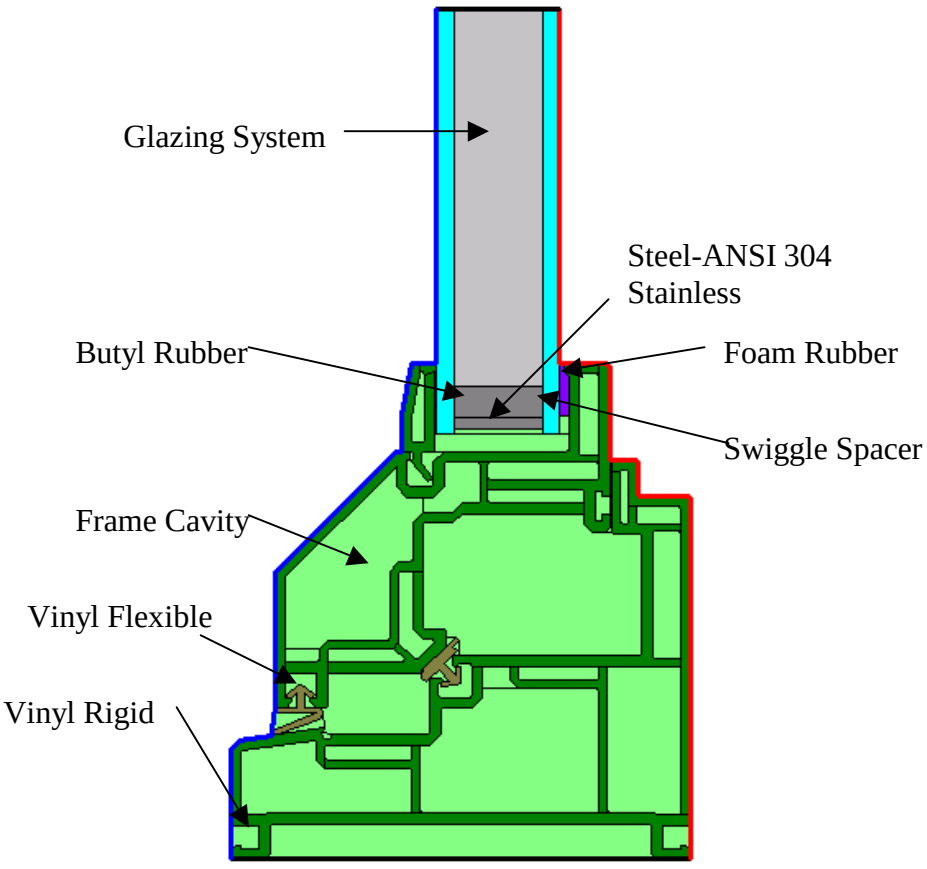


Figure 1: Schematic Representations Of Frame Materials In A Jamb Cross-Section Of Frame

Table 1: Material Thermo Physical Properties

Material	*k* (Btu/h-ft-F)	ε
PVC/Vinyl (Rigid)	0.0982	0.9
Foam Rubber	0.0173	0.9
Butyl Rubber	0.1387	0.9
Silica Gel (desiccant)	0.0173	0.9
Steel-ANSI 304 Stainless	8.2625	0.2
Vinyl (Flexible)	0.0693	0.9

The boundary conditions used in the U-Factor and CR calculations are listed in Table2.

Table 2: Boundary Conditions For Indoor And Outdoor Side Of Window System For U-Factor Calculation And CI Calculation

Boundary Conditions		*Environmental Temperature (F)*	h_c	*Overall h*	ε
			(Btu/h-ft^2-F)		
Outdoor Side	Glazing	0	4.578	N/A	0.84
	Frame		4.578	N/A	0.90
Indoor Side	Glazing	70	0.446	N/A	0.84
	Frame		0.446	N/A	0.90

The isotherms for different cross sections of the window system for U-factor calculations are shown in Figure 2.

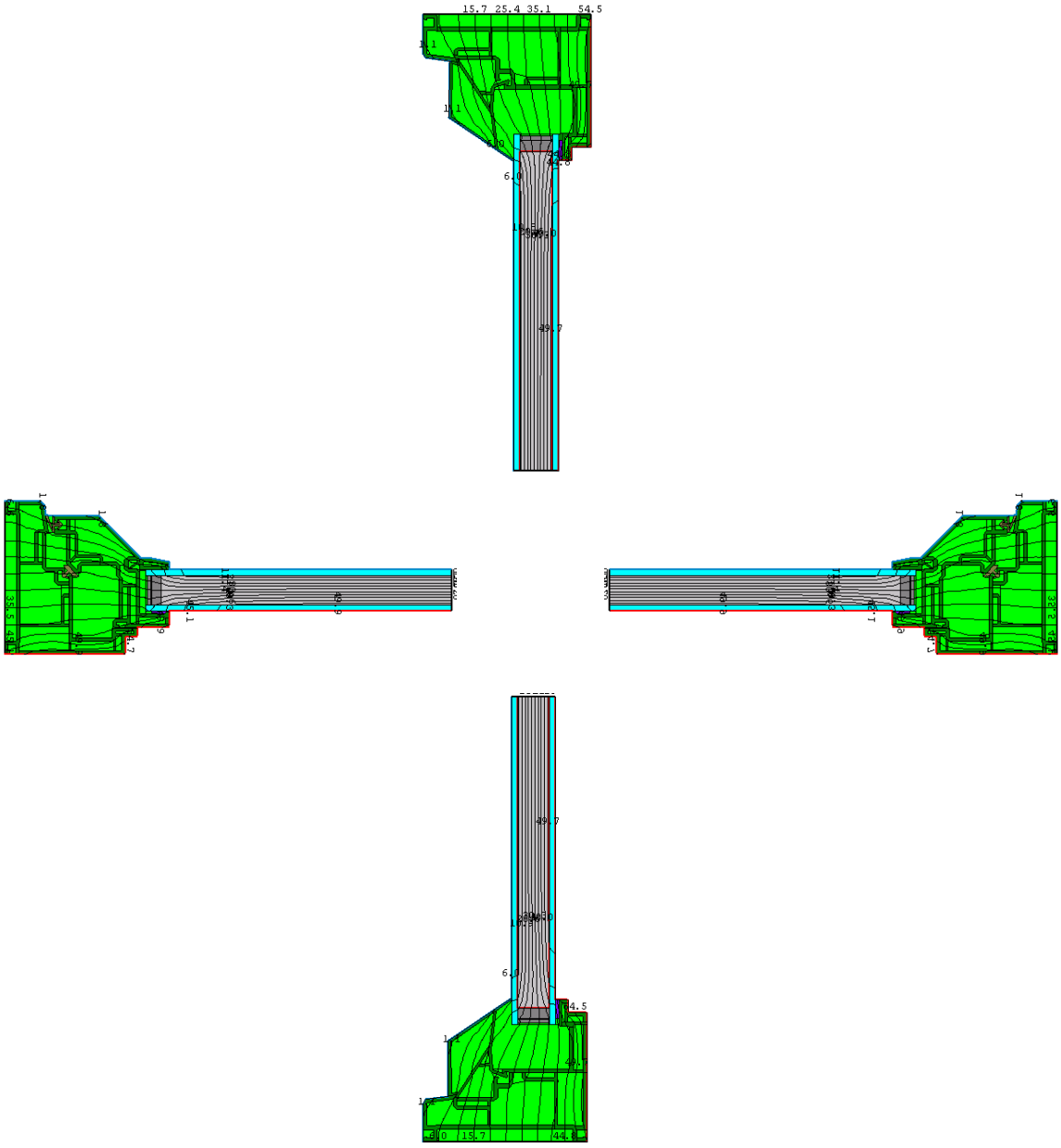


Figure 2: Isotherms for Head, Jamb and Sill Cross Sections of The Window System for U-factor Calculation

The frame and edge cross-sections U-factors and overall U-factors for the window are given in Tables 3.

Table 3: Frame, Edge And Overall U-Factors

Cross Section	*Project Y of frame(inches)*	***U-factor of frame(Btu/h-ft^2-F)***	***U-factor of edge-of-glass(Btu/h-ft^2-F)***
Head	2.8130	0.2975	0.3487
Sill	2.8130	0.2929	0.3438
Jamb	3.5000	0.3075	0.3465
	U-Factor (Btu/h-ft^2-F)	***SHGC***	***VT***
Center of glass	0.303	0.401	0.614
Window assembly	**0.313**	**0.263**	**0.384**

The isotherms for different cross sections of the window system for CR calculations are shown in Figure 3.

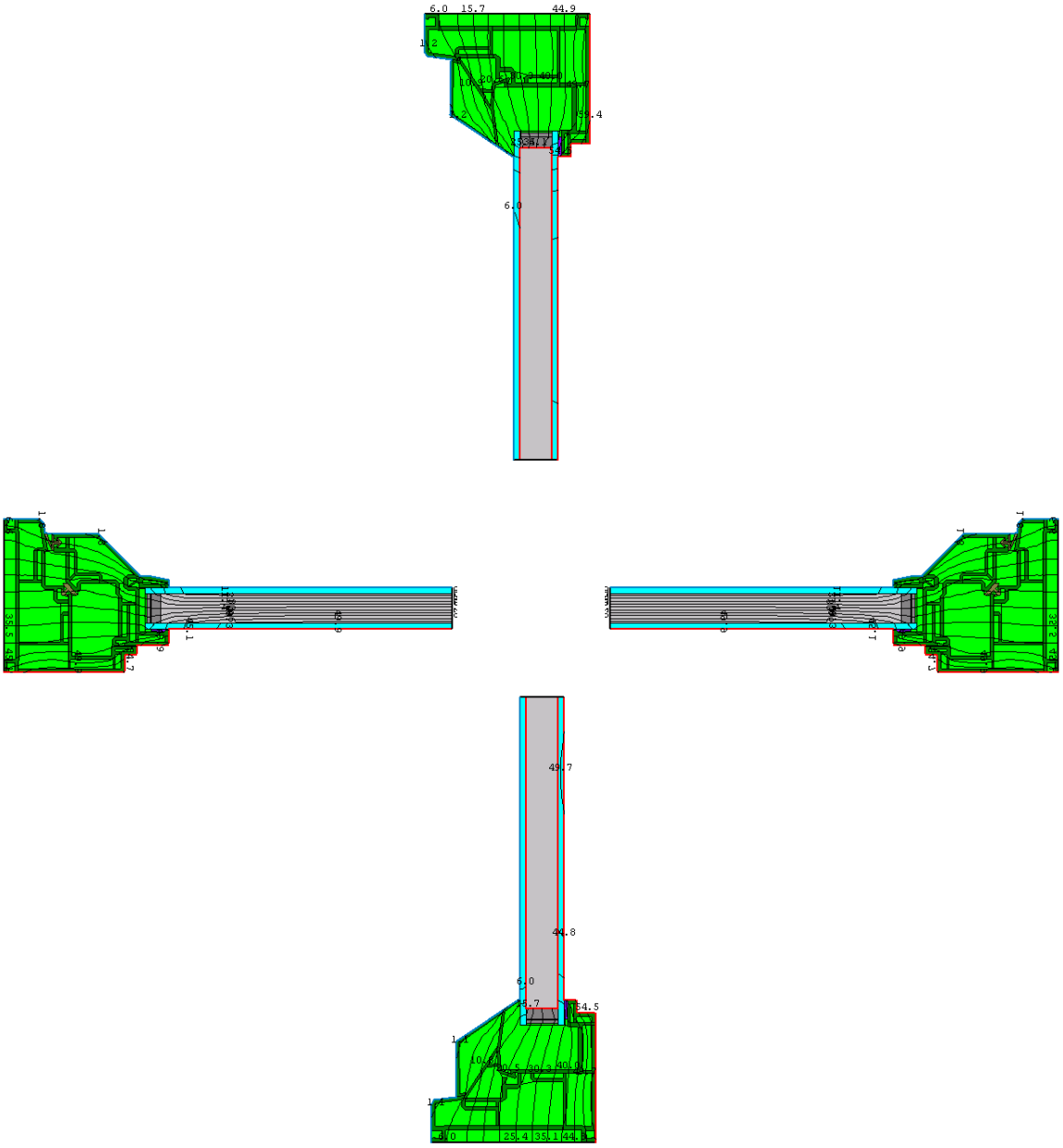


Figure 3: Isotherms for Head, Jamb and Sill Cross Sections of The Window System for CR Calculation

The results of CI calculation obtained are given in Table 4.

Table 4: CI Results Using Therm2+W4 Heat Transfer Coefficients

CI	**Window5**	**Spreadsheet**
CI_f	69.86	69.77
Ci_g	65.58	65.21
CI_e	58.44	57.97
CI	58	58

COMPARISON WITH TEST DATA:

Figure 4 and Figure 5 show the temperature variation along the inside surface for the window system. The middle point in the graph corresponds to the center of glass temperature. Distance at X-axis corresponds to either the bottom of sill section to the top of the head section, or the left jamb section to the right jamb section. Temperature data obtained from the test are also plotted in the figures.

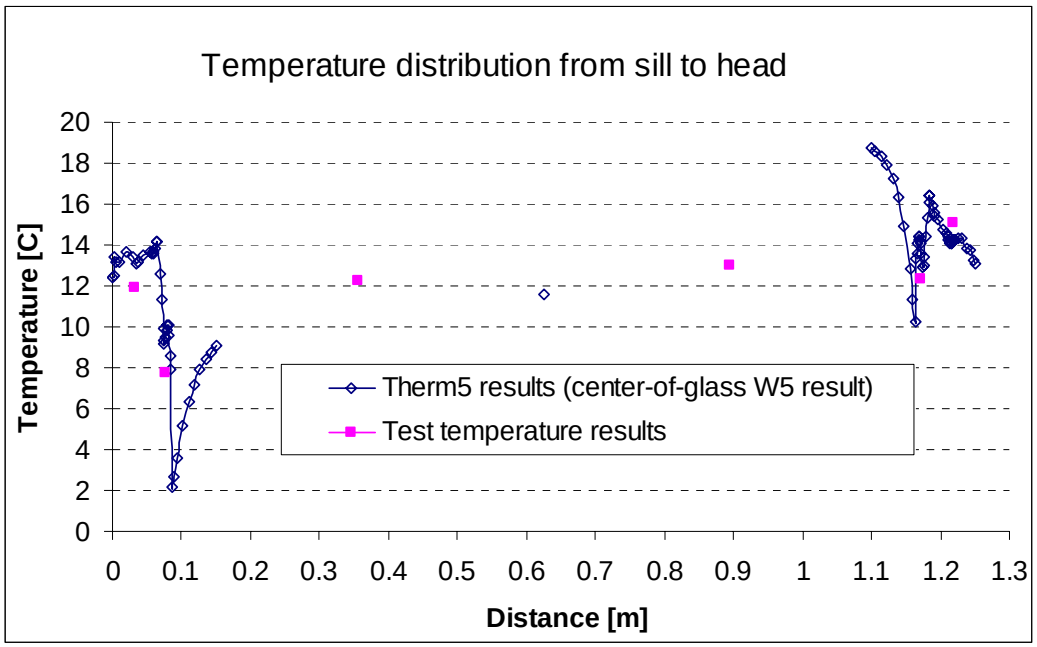


Figure 4. Temperature Distributions along Inside Surface (From Sill to Head)

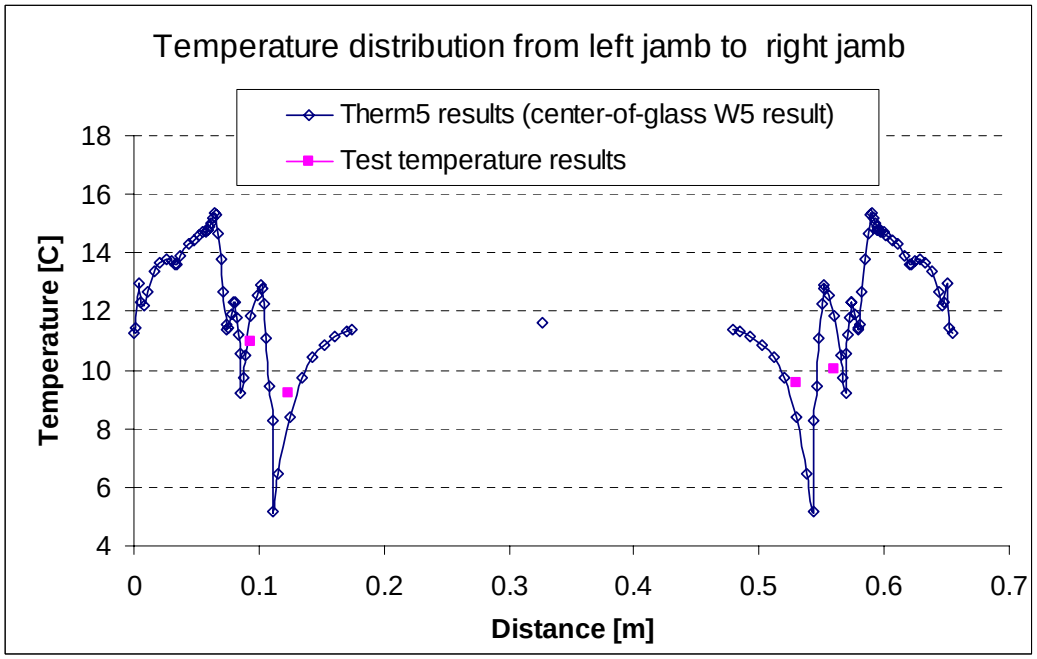


Figure 5. Temperature Distribution along Inside Surface (From Left Jamb to Right Jamb)

Appendix A– Window5 Report


```
       ID: 8
     Name: PVC
  EnvCond: 1 NFRC 100-2002

     Type: Casement, custom
     Tilt:  90
     Size: 0
    Width: 609.6 mm
   Height: 1219.2 mm
     Area:  0.74 m2


  U-value: 1.778 W/m2-K
     SHGC: 0.263
       Vt: 0.384
       CI:  58.4
```

Data for Glazing Systems

ID	Name	COG Area m2	#Lay	Tilt	Uc W/m2	SCc	SHGCc	Vtc	RHG
11	PVC	0.289	2	90	1.719	0.46	0.40	0.61	302

Glass and Gas Data for Glazing System '11 PVC'

ID	Name	D(mm)	Tsol	1 Rsol	2 Rsol	Tvis	1 Rvis	2 Tir	1 Emis	2 Keff
Outside										
970	FPVC_lowE.AFG	3.2	.411	.391	.457	.672	.249	.189	.000	.840	.036	.900
1	Air	15.9								
107	PVC_clear.DAT	3.2	.834	.075	.075	.899	.083	.083	.000	.840	.840	.900
Inside										

Frame Data

Location	ID	Name	Source	Frame Area m2	Edge Area m2	Uframe W/m2-K	Uedge W/m2-K
Header	8	PVCHead.THM	Therm	0.037	0.023	1.6893	1.9799
Left Jamb	9	PVCJamb.THM	Therm	0.102	0.064	1.7446	1.9675
Right Jamb	9	PVCJamb.THM	Therm	0.102	0.064	1.7446	1.9675
Sill	10	PVCSill.THM	Therm	0.037	0.023	1.6634	1.9525

Gas Data

ID	Name	Type	Cond W/m-K	Visc kg/m-s	Cp J/kg-K	Dens kg/m3	Pran
1	Air	Pure	0.0241	0.0000	1006.1033	1.2883	0.7197

Environmental Conditions: 1 NFRC 100-2002

	Tout (C)	Tin (C)	WndSpd (m/s)	Wnd Dir	Solar (W/m2)	Tsky (C)	Esky
Uvalue	-18.0	21.0	5.50	Windward	0.0	-18.0	1.00
Solar	32.0	24.0	2.80	Windward	783.0	32.0	1.00

Frame Library Data

ID	Name	Source	U-value Frame W/m2-K	U-value Edge W/m2-K	Edge Corr	GlzSys Width mm	GlzSys Uc W/m2-K	Width (PFD) mm	Abs
8	PVCHead.THM	Therm	1.6893	1.9799	N/A	22.225	1.719	71.45	0.50
9	PVCJamb.THM	Therm	1.7446	1.9675	N/A	22.225	1.719	88.90	0.50
10	PVCSill.THM	Therm	1.6634	1.9525	N/A	22.225	1.719	71.45	0.50

Divider Library Data

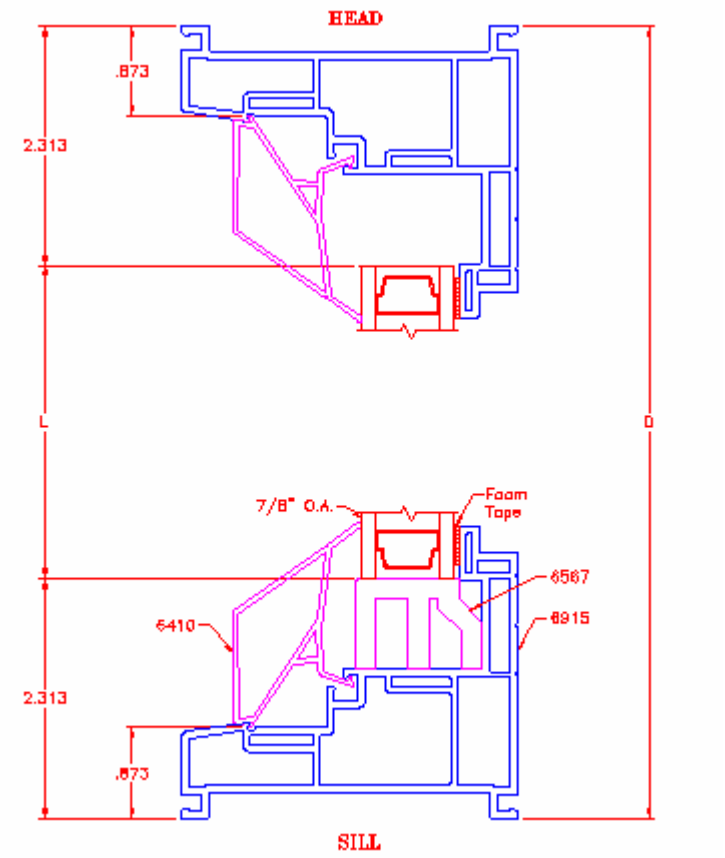
ID	Name	Source	U-value Div W/m2-K	U-value Edge W/m2-K	Edge Corr	GlzSys Width mm	GlzSys Uc W/m2-K	Width (PFD) mm	Abs

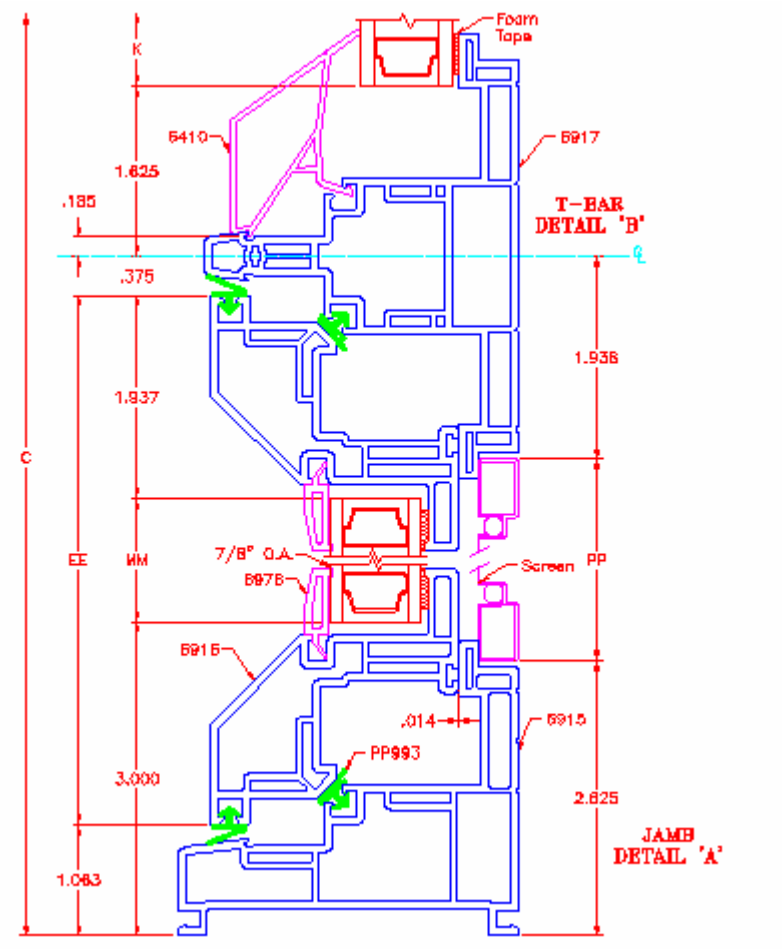
No Dividers for this Glazing System

Temperature Distribution (degrees C)

	Winter Out	Winter In	Summer Out	Summer In
Lay1	-15.7	-15.5	38.8	39.0
Lay2	11.4	11.6	30.4	30.3

Appendix B -- Autocad drawing


HEAD
.873
2.313
L
D
7/8" O.A.
Foam
Tape
6567
6915
6410
2.313
.873
SILL



Appendix C--Test Report

NFRC 100-97 THERMAL PERFORMANCE
TEST REPORT

Rendered to:

ANLIN INDUSTRIES

SERIES/MODEL: "CORONADO"
TYPE: Vinyl (PVC) Casement Window

Report No: **03-31354.04**
Report Date: **12-21-01**
Expiration Date: **11-13-05**

NFRC 100-97 THERMAL PERFORMANCE TEST REPORT

Rendered to:

Anlin Industries
1665 Tollhouse Road
Clovis, California 93611

Report No: 03-31354.04
Test Date: 11-13-01
Report Date: 12-21-01
Expiration Date: 11-13-05

Test Sample Identification:

Series/Model: "Coronado"

Type: Vinyl (PVC) Casement Window

Overall Size: 2' 0" wide by 4' 0" high

Representative Size: Residential

Test Procedure: U-factor tests were performed in a Guarded Hot Box in accordance with NFRC 100-97, *Procedure for Determining Fenestration Product Thermal Properties.*

Test Results Summary:

Standardized U-factor (U_{st}): 0.31 Btu/hr·ft^2·F (CTS Equivalent Procedure)

Test Sample Description:

Construction:

		Frame	Vent
	Size	2' 0" x 4' 0"	1' 9-3/4" x 3' 9-7/8"
CORNERS		Mitered	Mitered
	Fasteners	Welded	Welded
	Sealant	None	None
MATERIAL		VY	VY
	Color Exterior	White	White
	Finish Exterior	Vinyl	Vinyl
	Color Interior	White	White
	Finish Interior	Vinyl	Vinyl
GLAZING METHOD		**NA**	Exterior glazed onto bed of silicone, held-in-place with vinyl glazing bead.

Glazing: (Sheet #1 is Exterior Sheet)

	Sheet #1	Gap #1	Sheet #2
THICKNESS	0.125"	0.625"	0.125"
COATING EMISSIVITY	0.036 *	NA	NA
COATING SURFACE	2	NA	NA
SPACER/SEALANT	NA	S5	NA
MATERIAL	Annealed glass	Air *	Annealed glass

Gas Filling Technique*: NA

** - Stated per Client/Manufacturer NA-Non Applicable See Appendix A for Description Codes*

Test Sample Description: (Continued)

Components:

Type	Quantity	Location
WEATHERSTRIP		
Polypile with center fin	1 Row	Perimeter of vent
Single leaf gasket	1 Row	Perimeter of vent
HARDWARE		
Lock assembly	1	Lock stile
Roto-operator	1	Bottom rail
Multi-bar hinge assembly	2	**Top and bottom rails**
DRAINAGE		
0.375" x 0.100" weep hole	2	Each end of vent rail

Test Conditions:

t_{ll}	= Average weather side ambient temperature	0.06	F
t_l	= Average room side ambient temperature	70.01	F
	Metering room average relative humidity	7.72	%

- Nominal 15-mph dynamic wind applied perpendicular to the test specimen exterior.
- Specimen was sealed during testing using clear tape.
- The pressure created by the dynamic wind was offset to create a pressure difference across specimen to 0.00" ± 0.04" H_2O, using make-up air.

Test Data:

A_s	= Projected specimen area	8.00	Ft^2
A_{sp}	= Area of surround panel	28.20	Ft^2
A_{mb}	= Metering box area	36.20	Ft^2
A_{b1}	= Area of warm side baffle	32.13	Ft^2
	Q = Total measured input to meter box	290.273	Btu/hr
Q_{sp}	= Surround panel heat loss	94.508	Btu/hr
Q_{mb}	= Metering box heat loss	12.827	Btu/hr
	Q_{fl} = Flanking loss	10.174	Btu/hr
Q_s	= Net specimen heat loss	172.764	Btu/hr
U_s	= Thermal Transmittance of test specimen	0.309	$Btu/hr \cdot ft^2 \cdot F$
R_s	= Thermal Resistance of the test specimen	3.239	$Btu/hr \cdot ft^2 \cdot F$
t_1	= Area-weighted warm side surface temperature	54.320	F
t_2	= Area-weighted cold side surface temperature	3.415	F
	Equivalent warm side surface temperature	54.533	F
	Equivalent cold side surface temperature	4.497	F
	Area-weighted cold side frame surface temperature	1.570	F
	Area-weighted warm side frame surface temperature	57.178	F
	Area-weighted cold side edge-of-glass temperature	6.520	F
	Area-weighted warm side edge-of-glass temperature	47.469	F

Area-weighted cold side center-of-glass temperature	3.618	F
Area-weighted warm side center-of-glass temperature	54.787	F
h_1 = Warm side surface conductance	1.395	Btu/hr·ft^2·F
h_{11} = Cold side surface conductance	4.870	Btu/hr·ft^2·F
C_s = Thermal conductance of specimen	0.432	Btu/hr·ft^2·F
R_c = Surface-to-surface thermal resistance of specimen	2.317	hr·ft^2·F/Btu
R_1 = Warm side surface resistance	0.717	hr·ft^2·F/Btu
R_{11} = Weather side surface resistance	0.205	hr·ft^2·F/Btu
R_u = Overall thermal resistance of specimen	3.252	hr·ft^2·F/Btu
t_{b1} = Area-weighted baffle surface temperature	70.26	F
t_{sp1} = Surround panel warm side temperature	67.86	F
t_{sp2} = Surround panel cold side temperature	0.29	F
h_{st1} = Warm side standardized surface conductance	1.354	Btu/hr·ft^2·F
h_{st11} = Cold side standardized surface conductance	5.100	Btu/hr·ft^2·F
U_{st} = Standardized thermal transmittance of test specimen	0.308	Btu/hr·ft^2·F

$$R_{st} = \frac{1}{h_{st1}} + \frac{1}{C_s} + \frac{1}{h_{st11}}$$

$$U_{st} = \frac{1}{R_{st}}$$

The reported standardized thermal transmittance (U_{st}) was determined using the CTS equivalent calculation procedure.

Glazing Deflection:

	Glazing
Glazing thickness at edge	0.875"
Center glazing thickness upon receipt of specimen in laboratory (after stabilization)	0.910"
Center glazing thickness at laboratory ambient conditions on day of testing	0.910"
Center glazing thickness at test conditions	0.890"

Attached to this report is an isometric drawing indicating thermocouple attachment locations and average surface temperature measurements.

The test sample was inspected for the formation of frost or condensation which may influence the surface temperature measurements. Any observed condensation/frost is indicated on the attached drawing if applicable.

A calibration of the Fresno, California, ATI "thermal test chamber" was conducted in November 2000.

"This test method does not include procedures to determine the heat flow due to either air movement through the specimen or solar radiation effects. As a consequence, the thermal transmittance results obtained do not reflect performances which may be expected from field installations due to not accounting for solar radiation, air leakage effects, and the thermal bridge effects that may occur due to the specific design and construction of the fenestration system opening. The latter can only be determined by on-site measurements. Therefore, it should be recognized that the thermal transmittance results obtained from this test method are for ideal laboratory conditions and should only be used for fenestration product comparisons and as input to thermal performance analyses which also include solar, air leakage and thermal bridge effects".

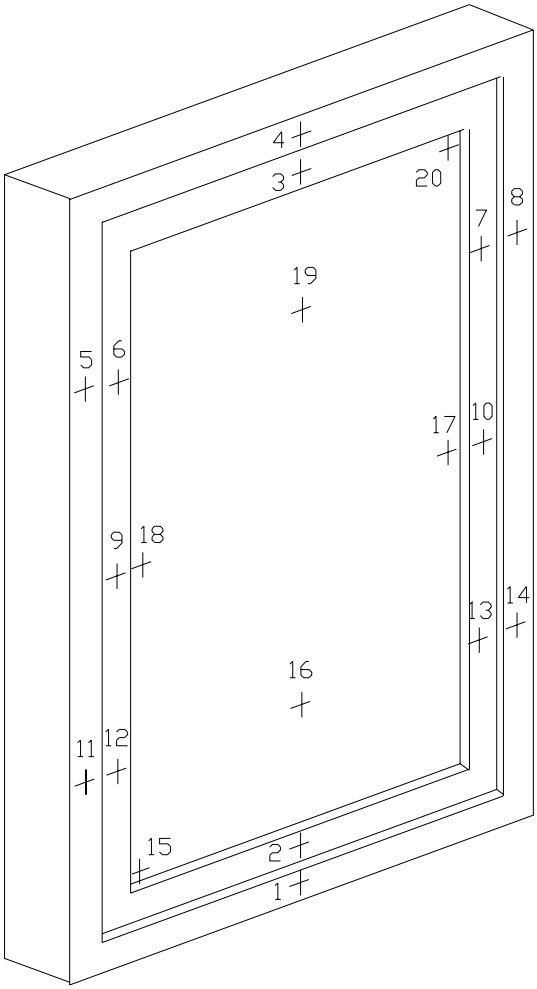
This report is reissued in the name of Anlin Industries through written authorization from Mikron Industries for whom testing was originally performed. The original Mikron Industries report number is 03-31354.01.

Detailed drawings, representative samples of the test specimen and a copy of this report will be retained by ATI for a period of four years. This report is the exclusive property of the client so named herein and is applicable to the sample tested. This report may not be reproduced, except in full, without the approval of the laboratory. ATI is an NFRC accredited test laboratory; all tests were conducted in compliance with NFRC approved procedures. Results obtained are tested values and do not constitute an opinion or endorsement by this laboratory. This report does not constitute certification of this product which may only be granted by an NFRC approved Independent Administrator.

For ARCHITECTURAL TESTING, INC.

Anthony Avalos Technician	Leaton Kirk Regional Manager

AA:lg



03-31354.04

Temperature (°F)

	Interior	*Exterior*
1	53.45	0.73
2	45.94	1.25
3	54.26	2.03
4	59.18	1.26
5	61.53	1.58
6	54.89	2.13
7	56.61	2.10
8	61.41	2.03
9	51.74	1.70
10	50.11	1.66
11	57.13	0.72
12	51.03	1.32
13	50.97	1.44
14	57.46	1.26
15	39.41	5.19
16	54.10	3.53

	17	49.18	5.38

Thermocouple Location Diagram

Architectural Testing, Inc. 03-31354.04	18	48.64	5.96
Anlin Industries	19	55.47	3.70
Coronado, Vinyl casement window	20	52.65	9.55

Appendix A
Description of Table Abbreviations

COD	FRAME/PANEL MATERIAL	DEFINITION
AI	Aluminum w/ vinyl inserts	Vinyl inserts employed in aluminum
AL	Aluminum	No thermally broken frame/sash components
AP	Aluminum w/ thermal breaks - partial	Some frame/panel members thermally broken
AT	Aluminum w/ thermal breaks – all	All members contain thermal breaks
AV	Aluminum/vinyl composite	Aluminum members combined with vinyl
AW	Aluminum clad wood	Aluminum cladding covering primary wood
FG	Fiberglass	Fiber reinforced frame/panel members
OT	Other	Material not described in this lookup table
PL	ABS Plastic	ABS plastic frame/sash members
ST	Steel	Steel alloy members
VA	Vinyl w/ reinforcing – all members	Some frame/panel members contain
VC	Vinyl clad aluminum	Vinyl cladding covering primary aluminum
VH	Vinyl w/ reinforcing – horizontal	Only horizontal panel members contain
VI	Vinyl w/ reinforcing – interlock only	Only panel interlock members contain
VP	Vinyl w/ reinforcing – partial	Only specific members contain reinforcing
VV	Vinyl w/ reinforcing – vertical members	Only vertical panel members contain
VW	Vinyl clad wood	Vinyl cladding covering primary wood
VY	Vinyl	Vinyl members with no reinforcing
WA	Aluminum / wood composite	Aluminum members combined with wood
WD	Wood	All members are solid wood
WV	Vinyl / wood composite	Vinyl members combined with wood

CODE	INTERSPACE GAS FILL		CODE	THERMAL BREAK MATERIAL
AIR	Air		F	Foam
AR2	Argon / Krypton mixture		O	Other
AR3	Argon / Krypton / Air mixture		U	Urethane
ARG	Argon		V	Vinyl
CO2	Carbon Dioxide			
KRY	Krypton			
OT	Other			
SF6	Sulfur Hexaflouride			

CODE	SPACER TYPE	DEFINITION
A1	Aluminum	Aluminum spacer system
A2	Aluminum – thermally broken	Aluminum spacer with urethane thermal break
A3	Aluminum – reinforced polymer	Polymer spacer with aluminum substrate
A4	Aluminum / wood	Aluminum / wood composite
A5	Aluminum reinforced butyl	Butyl spacer with aluminum substrate
A6	Aluminum /foam/aluminum	Two aluminum spacers separated by foam
A7	Aluminum U shaped	U shaped aluminum spacer embedded in sealant
FG	Fiberglass	Fiberglass spacer system
GL	Glass	Glass spacer system
PU	Polyurethane foam	Polyurethane foam
S1	Steel	Stainless steel spacer system
S2	Steel – thermally broken	Stainless steel spacer with urethane thermal break
S3	Steel / foam / steel	Two steel spacers separated by foam
S4	Steel U shaped	U shaped stainless steel spacer system

S5	Steel reinforced butyl	Butyl spacer with steel substrate
V1	Vinyl U shaped	U shaped spacer system embedded in sealant
WD	Wood	Wood spacer system
ZF	Silicone foam	Silicone foam spacer system

DOCUMENT CONTROL ADDENDUM #03-31354.04

Current Issue Date: December 21, 2001

Report No.: 03-31354.01

Requested by: Jeff Franson
Purpose: NFRC 100-97 Thermal Performance test report
Issued Date: November 23, 2001
Comments: First Issue

Report No.: 03-31354.02

Requested by: Jeff Franson
Purpose: Reissue report to Anlin Industries
Issued Date: December 7, 2001
Comments: Copies of report issued to ALI (Jim Hicks)

Report No.: 03-31354.03

Requested by: Jeff Franson
Purpose: Make correction on Glazing Method
Issued Date: December 21, 2001
Comments: Copy of report issued to client only

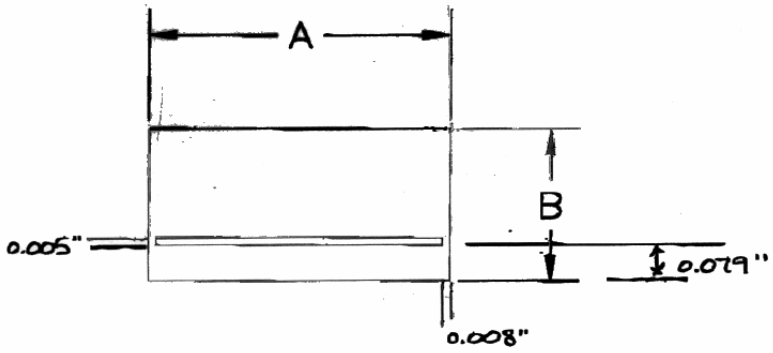
Report No.: 03-31354.04

Requested by: Jeff Franson
Purpose: Make correction on Glazing Method and reissue report to Anlin Industries
Issued Date: December 21, 2001
Comments: Copies of report issued to ALI (Jim Hicks)

Appendix D: Spacer Geometry and Details

MAY. -29' 02(WED) 15:43 ARCH. TESTING TEL:1-717-764-4129 P. 002

Swiggle Spacer



Material: Stainless Steel
Width (A): 0.625"
Height (B): 0.292"